SDA FOREST SERVICE
ESEARCH PAPER NC-122

GROWTH, DRY WEIGHT YIELDS, and SPECIFIC GRAVITY ... OF 3-YEAR-OLD POPULUS GROWN UNDER INTENSIVE CULTURE

DAVID H. DAWSON
J. G. ISEBRANDS
JOHN C. GORDON

ORTH CENTRAL FOREST EXPERIMENT STATION
OREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE

ABOUT THE AUTHORS

David H. Dawson is a Project Leader and Program Coordinator for the North Central Forest Experiment Station's Multiproject Program on Maximum Wood Yield Research at Rhinelander, Wisconsin. He has done research in the Northern Plains and Lake States and published in the fields of plant introduction, tree improvement, and effects of cultural treatment on tree yields. Before his present assignment he served as a research geneticist with the Station at Bottineau, North Dakota, and at Rhinelander in the Genetics of Northern Forest Trees Work Unit. He has Bachelors and Masters Degrees in Forestry and Resource Management from Michigan State University. Dawson is active in the Society of American Foresters, APA, U. S. Poplar Council, American Association for the Advancement of Science, Crop Science of America, and IUFRO.

J. G. Isebrands is a project scientist of the Pioneering Research Work Unit in physiology of wood formation located at Rhinelander, Wisconsin. He joined the Station in 1969 after receiving his PhD degree from Iowa State University in wood science and technology with a minor in statistics. Isebrands has published in the fields of wood anatomy, tree physiology, and quantitative forest biology, and is active in the Forest Products Research Society, TAPPI, International Association of Wood Anatomists, Botanical Society of America, and IUFRO.

John C. Gordon is a Professor of Forest Biology at Iowa State University. He is a plant physiologist and has performed research and published in the fields of biochemistry of secondary cell wall formation, growth active enzymes in woody plants, photosynthesis and respiration as related to tree development, and nitrogen metabolism in woody plant root systems. Previous to his present position he served as a research plant physiologist with the Forest Service Pioneering Project in Physiology of Wood Formation at Rhinelander, Wisconsin. He received his Bachelor's and PhD degrees from Iowa State University and performed graduate study at the University of Helsinki, Finland. He is active in the American Society of Plant Physiologists, Ecological Society of America, Society of American Foresters, and The American Association for the Advancement of Science.

North Central Forest Experiment Station
John H. Ohman, Director
Forest Service - U.S. Department of Agriculture
Folwell Avenue
St. Paul, Minnesota 55108

Manuscript approved for publication May 16, 1975

1976

GROWTH, DRY WEIGHT YIELDS, AND SPECIFIC GRAVITY OF 3-YEAR-OLD POPULUS GROWN UNDER INTENSIVE CULTURE

David H. Dawson, J. G. Isebrands, and John C. Gordon

A common goal in agriculture for some time has been to systematically "optimize" all the manageable factors of plant environment. This concept has led to maximum crop yields for a particular site. Conversely, in forestry, practical silviculture has been applied as a single practice, with the hope of improving yields of natural stands, or emulating natural stands in the form of plantations.

Although woody plants can have biomass yields comparable with those of annual crops (Gordon 1975), their full photosynthetic potential will be realized only through research that specifies new modes of culture (Larson and Gordon 1969). Maximum growth can be attained if woody plants with ideal characteristics are grown under the best environmental conditions possible in the field.

The environmental factors most easily manipulated under field conditions are soil moisture, soil nutrients, and plant spacing. Spacing is particularly important because it is easily manipulated and does much to determine tree form and wood quality (Larson 1962).

In the search for "optimum" environments for particular genotypes, the concept of the ideal plant type, or ideotype, has proven useful. The specification of ideal plant characteristics, for a given cultural environment, provides a target for selection and breeding. For example, an ideal wood fiber-producing tree would have the following characteristics: (1) rapid proliferation of leaves in the spring and late senescence of leaves in fall; (2) erect branching, acute leaf angles, and a high leaf area index for maximum solar radiation interception; (3) noncompetitiveness, so that each individual in a stand efficiently occupies only the space allocated to it; (4) maximum allocation of photosynthate to stem wood production; (5) maximum response to available nutrients, particularly nitrogen; and (6) desirable wood properties for proposed end product[1] (Dickmann 1975).

Several efforts have been made using the above concepts to exploit the greater interception of solar energy by employing high initial densities and short rotations (McAlpine *et al.* 1966, Smith and DeBell 1973).

The experiment reported here was conducted to determine the effects of plant spacings on the growth, dry weight yield and distribution, and specific gravity of a single *Populus* genotype (*Populus* 'Tristis #1') subjected to near-optimum field cultural conditions for 3 years in northern Wisconsin. Crist and Dawson (1975) have reported on 2-year results. Although there have been many spacing experiments with members of the genus *Populus*, we know of none that have included close spacings, intensive water and nutrient management and monitoring, and total assessment of yield of all plant components over short rotations. Our results show that yields much higher than those attained by conventional forestry methods are possible.

METHODS AND MATERIALS

The study was established in an irrigated nursery near Rhinelander, Wisconsin, in June, 1970, using 8-in. long, unrooted cuttings that were approximately 0.25 inch in diameter. Biweekly foliar analyses were

---

[1] *Philip R. Larson. Physiological parameters of intensive culture--theoretical and applied. In-Service Workshop on Intensive Culture, Rhinelander, Wis., Sept. 18-19, 1973.*

used to monitor nutrient status, and fertilizers were added throughout each growing season to maintain near-optimum in-plant nutrient levels (Dykstra 1972). Soil moisture was maintained near field capacity by frequent irrigation (fig. 1).

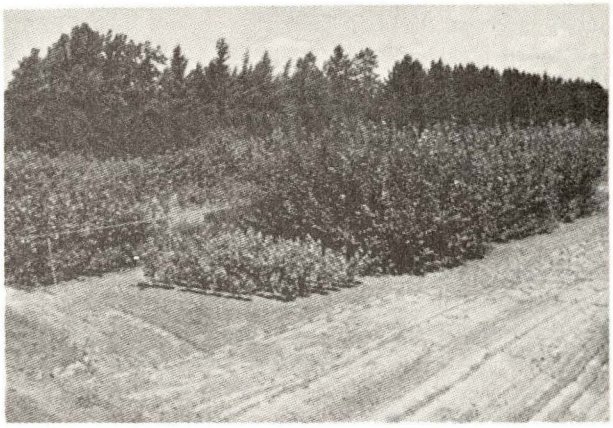

Figure 1.--*Three-yr-old plots of maximum-fiber-yield study.*

The study design was a randomized complete block with three replications. The plant spacings were 9 in. by 9 in. (77,440 plants/acre), 12 in. by 12 in. (43,560 plants/acre), and 24 in. by 24 in. (10,890 plants/acre) in 16-ft by 16-ft plots. Plots were kept small because of limited availability of plant material and resources. The spacings will hereafter be referred to as 9 by 9, 12 by 12, and 24 by 24.

Height and basal diameter were measured on a 10 percent sample of the trees in each plot six times during each growing season. To describe crown form, the following were measured on five additional trees per plot: shoot length, internode length, branch length, branch angle, and branch diameter.

After two full growing seasons (end of 1972), a 2-ft by 6-ft subplot was harvested from each of the plots.[2] Therefore, the number of trees harvested varied depending on the spacing. Trees were cut at ground level and the following measurements made and recorded for each tree: total height, stem diameter (base, midpoint, and 6 inches from the top); number of branches, length of the uppermost branch, the sixth branch from the top, and the bottom branch; height from base to bottom branch; and length of stem above top branch. At harvest, the stem and branches were cut into 3-ft lengths, wrapped in wet paper towels and polyethylene wrap, and placed in the freezer.

To analyze yield each tree was removed from the freezer and separated into the following components: stem wood, branch wood, stem bark, branch bark, tips (top 6 inches of stem), and dead stem wood. All components were ovendried at 70°C and then weighed. Dry weight yields were extrapolated to tons per acre by area expansion. Because the trees were harvested after leaf fall had begun, leaf dry weights were not included.

In addition, three discs were removed from three points on the stem (1 inch from the base, midpoint of the stem, and three internodes down from the tip) to determine specific gravity by the ovendry weight method--green volume basis using water immersion for volume determination.

RESULTS AND DISCUSSION

Growth

Little height growth occurred during 1970 because unrooted cuttings were planted in late spring and growth ceased in mid-July due to the inherent response of the genotype to the photoperiod in Wisconsin (Larson and Isebrands 1972). However, *Populus* 'Tristis #1' even when well established does not fully utilize the growing season of northern Wisconsin. For example, in 1971 and 1972, 90 percent of the terminal buds were set by the second week in August, several weeks before the first killing frost. Within the *Populus* genus, photoperiod has been considered to be the major factor in determining time of flushing and cessation of growth (Pauley and Perry 1954). However, studies by Dykstra (1974) indicated that annual height growth cessation and photosynthetic rate were also influenced strongly by nitrogen uptake. We believe the later date of growth cessation for 1971 and 1972, when compared to 1970, may be due

[2] *Although the first year was not a full growing season and can be regarded as a year of establishment, after two full growing seasons we consider the trees to be 3 years old. Furthermore, these plots were not a coppice crop; they consisted of only one stem per plant.*

to the higher and more constant levels of soil nitrogen being maintained during that period.

Average height growth between spacings was not significantly different until the third year and then the range was from about 10 feet for the highest density to about 12.5 feet for the lowest density (table 1). Significant differences in diameter growth showed up in the second growing season between the 24 by 24 spacings and the narrower spacings. At the end of 3 years the only mortality was in the 9 by 9 plots, which averaged 10 percent loss (fig. 2).

Crown Form

Number of branches, branch lengths, and branch angles were measured to ascertain the effects of competition on crown form at an early age. Although the number of branches did not vary significantly among spacings, branch length did (fig. 3). Differences in branch length between the 9 by 9 and 12 by 12 plots were nonsignificant (averages of 34 in. and 32 in., respectively); however, the 24 by 24 branches were significantly longer (44 in.).

Table 1.--*Mean basal diameter and height of 3-yr-old* Populus *'Tristis #1' grown at three spacings in irrigated and fertilized plots*

Spacing (Inches)	Basal diameter			Height		
	1970	1971	1972	1970	1971	1972
	Inches			*Feet*		
9 by 9	[1]0.32a	0.60a	0.84a	0.90a	5.80a	10.10a
12 by 12	.40a	.69a	.93a	.95a	5.86a	11.10b
24 by 24	.40a	.91b	1.32b	1.14a	6.17a	12.55c

[1] Figures within a column followed by the same letter indicate they are not significantly different at the 95 percent probability level.

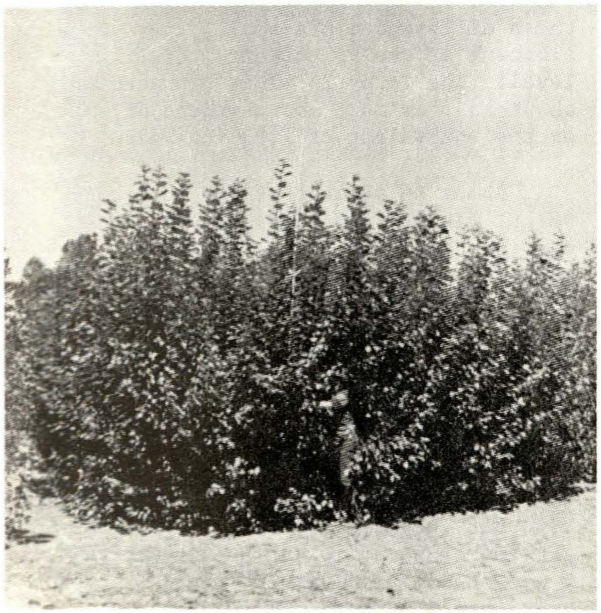

Figure 2.--*Three-yr-old plot of* Populus *'Tristis #1' planted at 9 in. by 9 in. spacing.*

Branch angles were influenced only at the lower levels of the crown; they were slightly more acute in the 9 by 9 and 12 by 12 spacings. Although figure 3 accurately portrays the branch lengths and branch angles, it should be noted that all long branches on the trees in the plots curve toward the vertical. This allows more leaves to intercept direct sunlight than indicated in the graphs.

Crown closure occurred in all spacings during the second growing season (1971) and by the middle of the third growing season, the lower levels of all plots were very dense (fig. 4).

YIELDS OF COMPONENTS

Dry Weight

The 9 by 9 and 12 by 12 plots produced the equivalent of 16.68 and 14.83 tons/acre, respectively, of above-ground dry matter exclusive of leaves (table 2). Although

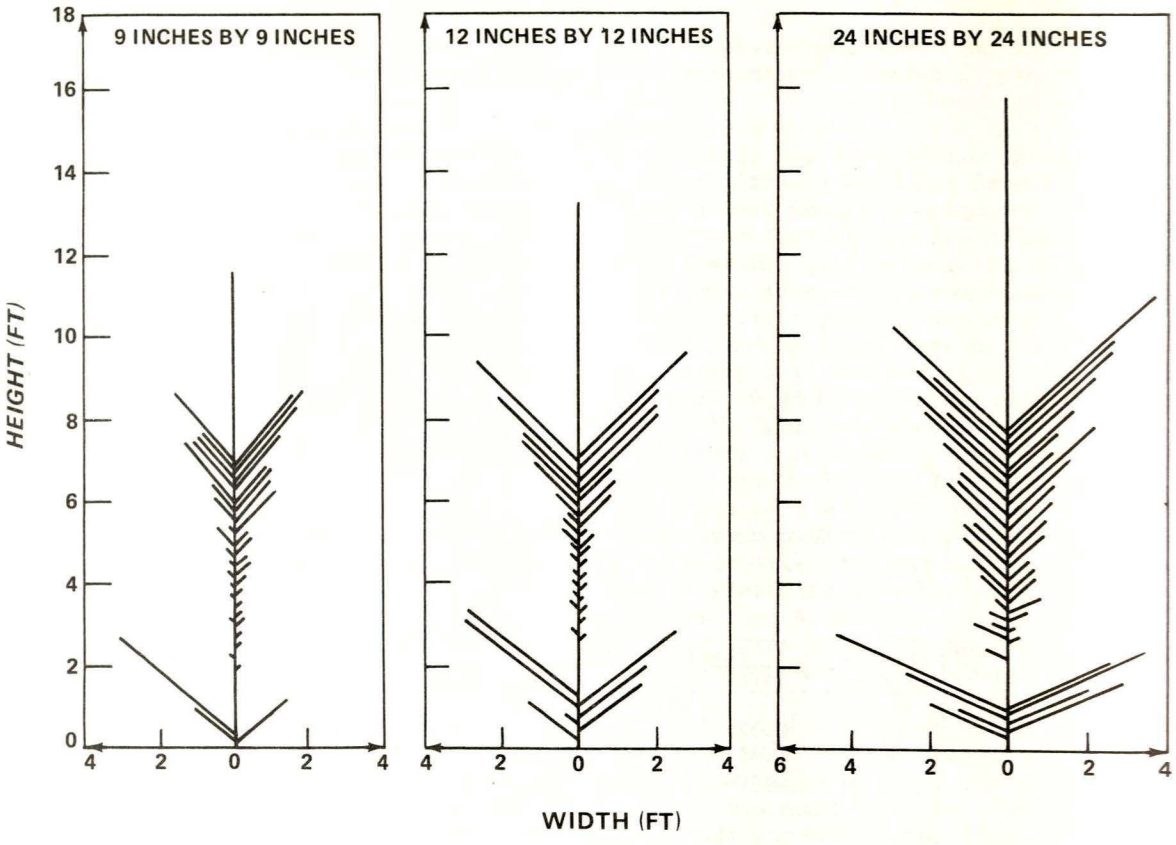

Figure 3.--*Crown form of typical 3-yr-old* Populus *'Tristis # 1'. Trees grown at three spacings in irrigated and fertilized plots.*

Figure 4.--*Photograph at ground level inside of 24 in. by 24 in. spaced plot showing closed crowns.*

these differences are small, they are significant at the 95 percent probability level. The 24 by 24 plots produced only about half as much above-ground dry matter or the equivalent of 7.93 tons/acre.

About 66 percent of the total dry weight yields from plots of all three spacings was wood. Considering the fact that the total dry weight in branches is different between spacings, it is meaningful to note that the percent of total dry weight in wood for all plots was the same (table 3). The above-ground yields (expressed in tons per acre) of wood from both stem and branches, was 11.1 for the 9 by 9 spacing, 9.8 for the 12 by 12 spacing and 5.3 for the 24 by 24 spacing. Considering that they grew for less than three full growing seasons, it can be assumed that the 9 by 9 plots produced the equivalent of over 4 tons of ovendried wood per acre per year. These yields tend to corroborate the hypothesis expressed by Gordon and Bentley (1970) that dense stands of narrow-crowned plants with acute branch and leaf angles

Table 2.--*Dry weight yields of 3-yr-old* Populus *'Tristis #1' grown in irrigated and fertilized plots*[1]

Spacing (Inches)	Stand density	Total dry weight[2]	Stem[2]			Branches[2]			Tips[3]	Dead woody material
			Total	Wood	Bark	Total	Wood	Bark		
	Trees/acre	*Tons/acre*	*Tons/acre*			*Tons/acre*			*Tons/acre*	*Tons/acre*
9 by 9	77,440	16.68	13.31	9.72	3.59	2.97	1.42	1.56	0.27	0.13
12 by 12	43,560	14.83	11.63	8.45	3.18	2.87	1.36	1.50	.25	.10
24 by 24	10,890	7.93	5.77	4.30	1.47	2.02	.99	1.03	.13	.01

[1] Average of three plots, oven dry weight.
[2] Extrapolated to tons/acre.
[3] Top 6 inches of stem.

Table 3.--*Total dry weights of components of 3-yr-old* Populus *'Tristis #1' grown in irrigated and fertilized plots*

(In percent)

Spacing (Inches)	Total tree				Stem		Branches	
	Stem	Branches	Tips[1]	Deadwood	Wood	Bark	Wood	Bark
9 by 9	80	18	1	1	73	27	47	53
12 by 12	79	19	1	1	74	26	47	53
24 by 24	73	25	1	1	74	26	48	52

[1] Top 6 inches of stem.

will approach maximum photosynthetic production of an area very quickly.

Our extrapolated yields are higher than reported for both natural and planted stands of pure or mixed *Populus*. For example, in this region Einspahr and Benson (1968) calculated the average growth for commercial forest land in the Lake States region to be 22 cubic feet (about 0.25 tons) per acre per year under the "short log" system. Yields are higher when total-tree harvesting systems were employed. Benson and Einspahr (1972) reported yields of 1,900 pounds (0.95 tons) of wood per acre per yr from an 18-yr-old aspen stand in northern Wisconsin. Similarly, Napier (1972) reported about 45 tons dry weight per acre, wood and bark, from a 45 to 50-yr-old aspen-red oak stand in Michigan, or about 1 ton/acre/yr. Furthermore, in the Pacific Northwest mean annual increments in dense thickets of 9 to 14-yr-old red alder were about 5.8 tons of ovendry stem wood, without bark, per acre (DeBell 1972).

A number of researchers have recently reported yields from dense plantations of intensively cultured hardwoods. For example, Schreiner (1970) reported 2.3 tons/acre/yr of peeled stem wood from plantations of hybrid poplars in the Northeast at 1 by 4 ft spacings. In Pennsylvania Bowersox and Ward (1968) reported 2.65 tons/acre/yr yields of ovendry peeled stem wood of 3-yr-old *Populus* grown at 0.5 by 2 ft spacings. Similarly, yields of above-ground material from 3-yr-old sycamore sprouts growing in the Southeast ranged from 3.8 tons/acre/yr in 4 by 4 ft spacing to 7.9 tons/acre/yr in 1 by 4 ft spacing (Saucier *et al.* 1972).

Wood/bark ratios both in stems and branches did not vary significantly between spacings (table 3). In stems there was about three times as much wood as bark, while in the branches there was slightly more bark than wood. This represents a large increase in the wood/bark ratio when compared to the first year results of Larson and Isebrands (1972). Eighty percent of the total dry weight in the 9 by 9 spacing was in the stem in contrast to 73 percent in the 24 by 24 spacing. This difference was significant. Young and Carpenter (1967) also reported 80 percent of dry weight in stems for *Populus tremuloides* from natural stands in similar height classes.

From a utilization standpoint, the percent of total wood in stems versus branches is significant, particularly if branches are less than 1 inch in basal diameter. Furthermore, the quality of pulp produced by small branches is lower than that produced by larger branches and stems (Keays 1971). As the wood content of branches decreases with decreasing diameter, the percent of bark and extractives increase, and the overall yield is lower. Also the costs of chipping and debarking small branches is characteristically high (Keays 1971) because of their small diameter. Hence, it would seem a reasonable management objective to regulate stands to maximize the amount of stem wood.

SPECIFIC GRAVITY

Specific gravity is an index of the amount of cell wall substance in the wood and is often used as a measure of wood quality. In *P.* 'Tristis #1' specific gravity varied considerably by stem position, but not significantly by plant spacing (table 4).

The average specific gravity of the basal portion of the stem, which contains the greatest volume of wood, ranged from 0.377 for the 9 by 9 to 0.403 for the 12 by 12; the 24 by 24 was slightly less at 0.401. At the midpoint of the stem the average specific gravity ranged from 0.353 to 0.361. The lowest average was found three internodes from the tip; although the volume from that point to the tip constitutes less than 1 percent of the total stem. Crist and Dawson (1975) reported that the mean specific gravity of wood from the base, midpoint, and 6 inches from the tip to be 0.402 for 2-yr-old shoots of *Populus* 'Tristis #1'; Larson and Isebrands (1972) reported a similar range in specific gravity in 1-yr-old sprout material from the same clone. Hence, the additional growing season seemed to have no great effect on specific gravity. Furthermore, it is important to note that high specific gravities at the stem base may reflect a high incidence of tension wood (Isebrands and Parham 1974).

In comparison, Einspahr *et al.* (1972) found specific gravities ranging from 0.277 to 0.340 in a 6-yr-old natural aspen sucker stand. In addition, Pronin (1971) reported specific gravity of cores extracted at breast height of twenty-eight 50-yr-old *Populus tremuloides* or *Populus grandidentata* trees in natural stands in Wisconsin ranged from 0.329 to 0.486. The specific gravity of all samples taken from the base or midpoint in the stem of *Populus* 'Tristis #1' in this study are within the range of these averages. It would appear that the utilization potential of 3-yr-old *P.* 'Tristis #1' grown in irrigated and fertilized stands may compare favorably with native stands of aspen.

SUMMARY AND MANAGEMENT IMPLICATIONS

The results of this preliminary study suggest that more wood can be produced for pulp manufacture under very short rotations and nearly optimal growing conditions than in natural stands.

Trees planted at the closest spacing (9 by 9) produced the most wood--the equivalent of over 4 tons/acre/year. This spacing also produced the largest percent of dry weight in the stem (70 percent).

Average height and diameters were significantly greater in the widest spaced plots (24 by 24).

Competition between plants is effective at a very early age, as evidenced by the variation in average tree size and form. The site appeared to be totally occupied by the *Populus* plants in all the plots by the end of the second growing season.

Table 4.--*Specific gravity of fertilized and irrigated 3-yr-old* Populus *'Tristis #1' shoots at three stem positions*

Spacing (Inches)	Three internodes from tip		Midpoint		Basal	
	Average:	Range	Average:	Range	Average:	Range
9 by 9	0.187	0.154-0.211	0.354	0.333-0.383	0.377	0.365-0.387
12 by 12	.193	.167- .214	.361	.341- .395	.403	.377- .404
24 by 24	.166	.133- .200	.353	.341- .357	.401	.380- .421

Specific gravity samples from the basal and middle portions of the trees fell within the range reported for natural stands of aspen.

These results have encouraged us to initiate larger, more comprehensive studies in this region to determine the best combination of clone, spacing, and rotation. Additional research is needed to find the optimum manageable environmental conditions for the combination. Properly oriented research studies could determine not only the biological parameters for intensive culture systems, but economic parameters as well.

LITERATURE CITED

Benson, M. K., and D. W. Einspahr. 1972. Yields from 18-year-old aspen via total tree harvesting. Genet. and Physiol. Note 14, 8 p. The Inst. Pap. Chem.: Appleton, Wis.

Bowersox, T. W., and W. W. Ward. 1968. Juvenile growth and yield of hybrid poplar clone, NE-388. Pa. State Univ. Res. Briefs 3:2-6.

Crist, J. G., and D. H. Dawson. 1975. Anatomy and dry weight of two *Populus* clones grown under intensive culture. USDA For. Serv. Res. Pap. NC-113, 6 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.

DeBell, D. S. 1972. Potential productivity of dense young thickets of alder. Res. Note 2, 7 p. Crown Zellerbach: Camas, Wash.

Dickmann, D. I. 1975. Plant materials appropriate for intensive culture of wood-fiber in the North Central region. Iowa State J. Res. 49(3)Pt. 2:281-286.

Dykstra, G. F. 1972. Critical nitrogen level of two *Populus* clones: growth, nitrate reductase, and allometric response. Ph.D. thesis. Iowa State Univ., Ames, Iowa.

Dykstra, G. F. 1974. Nitrate reductase activity and protein concentration of two *Populus* clones. Plant Physiol. 53:632-634.

Einspahr, D. W., and M. K. Benson. 1968. Management of aspen on 10-year rotations. J. For. 66:557-560.

Einspahr, E. W., M. K. Benson, and M. L. Harder. 1972. Influence of irrigation and fertilization on growth and wood properties of quaking aspen. In Effect of Growth Acceleration on Properties of Wood Symp. Proc. Sec. I. p. 1-10. Madison, Wis.

Gordon, J. C. 1975. The productive potential of woody plants. Iowa State J. Res. 49(3)Pt. 2:267-274.

Gordon, J. C., and W. Bentley. 1970. Wood production in an industrial society. Univ. Wis. For. Res. Note 150, 2 p.

Isebrands, J. G., and R. A. Parham. 1974. Tension wood anatomy of short-rotation *Populus* spp. before and after kraft pulping. Wood Sci. 6:256-265.

Keays, J. L. 1971. Complete-tree utilization: an analysis of the literature. Part III: Branches. Info. Rep. VP-X-71, 67 p. Can. For. Serv. For. Prod. Lab., Vancouver, B.C.

Larson, P. R. 1962. A biological approach to wood quality TAPPI 45:443-448.

Larson, P. R., and J. C. Gordon. 1969. Photosynthesis and wood yield. Agric. Sci. Rev. 7:7-14.

Larson, P. R., and J. G. Isebrands. 1972. The relation between leaf production and wood weight in first-year root sprouts of two *Populus* clones. Can. J. For. Res. 2:98-104.

McAlpine, R. G., C. L. Brown, A. M. Herrick, and H. E. Ruark. 1966. Silage sycamore. For. Farmer 26:6-7, 16.

Napier, D. A. 1972. Total tree harvesting doubles fiber tonnage from aspen stand. J. For. 70:343-344.

Pauley, S. S., and T. O. Perry. 1954. Ecotypic variation of the photoperiod response in *Populus*. J. Arnold Arbor. 35:167-188.

Pronin, D. 1971. Estimating tree specific gravity of major pulpwood species in Wisconsin. USDA For. Serv. Res. Pap. FPL-161, 17 p. For. Prod. Lab., Madison, Wis.

Saucier, J., A. Clark, and R. McAlpine. 1972. Above-ground biomass yields of short rotation sycamore. Wood Sci. 5:1-6.

Schreiner, J. 1970. Mini-rotation forestry. USDA For. Serv. Res. Pap. NE-14, 32 p. Northeast. For. Exp. Stn., Upper Darby, Pa.

Smith, J. H. G., and D. S. DeBell. 1973. Opportunities for short rotation culture and complete utilization of seven northwestern tree species. For. Chron. 49:31-33.

Young, H. E., and P. M. Carpenter. 1967. Weight, nutrient element and productivity studies of seedlings and saplings of eight tree species in natural ecosystems. Maine Agric. Exp. Stn. Tech. Bull. 28, 39 p. Univ. Maine, Orono.

☆U.S. GOVERNMENT PRINTING OFFICE: 1975—668-898/101

Dawson, David H., J. G. Isebrands, and John C. Gordon. 1976. Growth, dry weight yields, and specific gravity of 3-year-old *Populus* grown under intensive culture. USDA For. Serv. Res. Pap. NC-122, 7 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.

In a nearly optimal cultural environment, *Populus* 'Tristis #1' grown for 3 years, planted at 9 by 9 inch spacing produced the equivalent of over 4 tons/acre/year of ovendry wood with specific gravity comparable to native aspen wood. Trees planted at wider spacings yielded less.

OXFORD: 232.43:525.5:812.31:176.1 *Populus* sp. KEY WORDS: spacing-effects, plant-density, short-rotation forestry, maximum yield.

Dawson, David H., J. G. Isebrands, and John C. Gordon. 1976. Growth, dry weight yields, and specific gravity of 3-year-old *Populus* grown under intensive culture. USDA For. Serv. Res. Pap. NC-122, 7 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.

In a nearly optimal cultural environment, *Populus* 'Tristis #1' grown for 3 years, planted at 9 by 9 inch spacing produced the equivalent of over 4 tons/acre/year of ovendry wood with specific gravity comparable to native aspen wood. Trees planted at wider spacings yielded less.

OXFORD: 232.43:525.5:812.31:176.1 *Populus* sp. KEY WORDS: spacing-effects, plant-density, short-rotation forestry, maximum yield.

AMERICAN REVOLUTION BICENTENNIAL
1776-1976